VARIATION IN PERFORMANCE OF MEDIA BASED STORMWATER TREATMENT SYSTEMS

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INTRODUCTION

Stormwater treatment systems (STSs) are being integrated across our urban landscapes in New Zealand and around the world with the intent of contaminant removal. Consistent downstream water quality and ecological health improvements are expected to follow STS installation; however, this is often not the case due to variability in treatment performance. A major source of variability in treatment performance comes from variation in contaminant load, which is a function of local climate and storm attributes as well as activities and changes in a catchment (Jefferson et al., 2017). Another source is variation in treatment systems themselves, which can be as wide ranging as the temporal differences in maintenance, age, and installation quality between units, and as detailed as the range of contaminants removed at a given location compared to another. Quantification of the variability witnessed in treatment performance and the determination of its sources can not only help designers to build and select more optimal treatment systems for a given location, but can also help planners set realistic expectations to improvements in water quality from investment.

Zinc is a priority metal of concern in Christchurch's urban waterways as identified by Christchurch City Council, and non-point source runoff from roofs contributes a substantial amount of the total load (Margetts and Marshall, 2018). While zinc occurs naturally in the aquatic environment, overexposure through bioaccumulation can lead to adverse health effects in humans and is toxic to aquatic organisms from microorganisms to vertebrates (Harding, 2005, Seto et al., 2013). Recent research suggests crushed mussel shells have a capability of removing dissolved zinc from stormwater runoff (Bremner et al., 2020). This ongoing study seeks to identify and quantify the impact of the most influential variables affecting the removal of dissolved zinc within two proprietary, at-source STSs: the Storminator™ developed at the University of Canterbury (UC), and the StormFilter™ sold by Stormwater 360.

METHODS

To test the STS's performance of dissolved zinc removal, a 256 m^2, galvanized roof was selected and the two pairs of STSs were installed to treat runoff from its four downpipes near the Department of Civil & Natural Resources Engineering (CNRE) at the UC in Christchurch, NZ (Figure 1). Flow was monitored by specially built weir boxes and runoff from the entire event was captured. The media based STS's were filled with a crushed mussel shell substrate (Table 1). The Storminators™ rely on gravity filtration while the StormFilters™ are activated by an internal syphon that draws water through the internal media until empty (Figure 2).

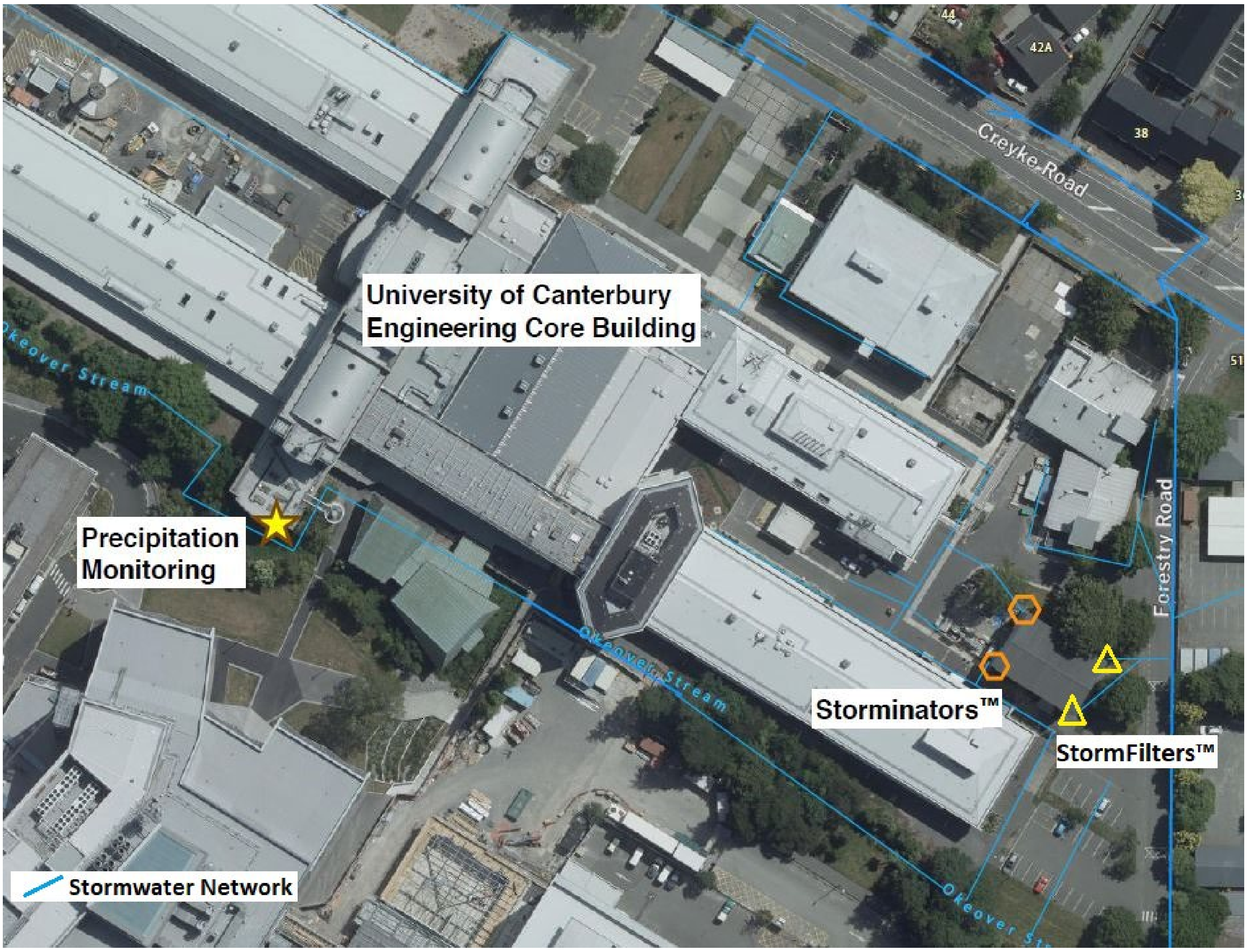

Figure 1: The research location at the University of Canterbury. Storminators™ were located on the north west and south west corners (SN-NW2, SN-SW1 & SN-SW2) while StormFilters™ were located on the north-east and south-east corners (SF-NE & SF-SE).

Table 1: Details of STSs installed and tested over the course of the study.

Code	SN-SW1	SN-SW2	SN-NW2	SF-SE	SF-NE
Type	Storminator™	Storminator™	Storminator™	StormFilter™	StormFilter™
Install dates	16/3/20 to 7/8/20	7/8/20 to present	17/6/20 to present	12/8/20 to present	16/9/20 to present
Media	Fresh, dried, crushed mussel shells	Aged, weathered, mussel shells	Aged, weathered, mussel shells	Aged, weathered, mussel shells	Aged, weathered, mussel shells
Location	South-west downpipe	South-west downpipe	North-west downpipe	South-east downpipe	North-east downpipe
Permeability / Max Flow	90 m/hr	40 m/hr	50 m/hr	Reduced to 0.35 L/s	Reduced to 0.35 L/s

The 5° roof directed water to the north and south where it flowed via PVC gutters into downpipes. Runoff was diverted through leaf diverters, and into weir boxes to split and monitor the flow at 1-minute intervals. One weir passed ~80% of the flow through a STS before being captured in a 1,000 L storage container (i.e. treated runoff quality) while the remaining ~20% was diverted directly into a 320 L storage container to quantify untreated runoff quality. Following a storm, each storage container was mixed and event mean concentration (EMC) samples collected. Samples were prepared for ICP-MS analysis of dissolved and total metals in the nearby CNRE environmental laboratory using APHA methods 3030 B & E and 3125 B (Baird & Bridgewater 2017). pH, conductivity and alkalinity were also measured from each storage container. Precipitation, wind and temperature were recorded at the rooftop CNRE weather station located within 200 m of the sample collection sites (Figure 1). Multi-variate linear regression analysis was conducted on the collected data.

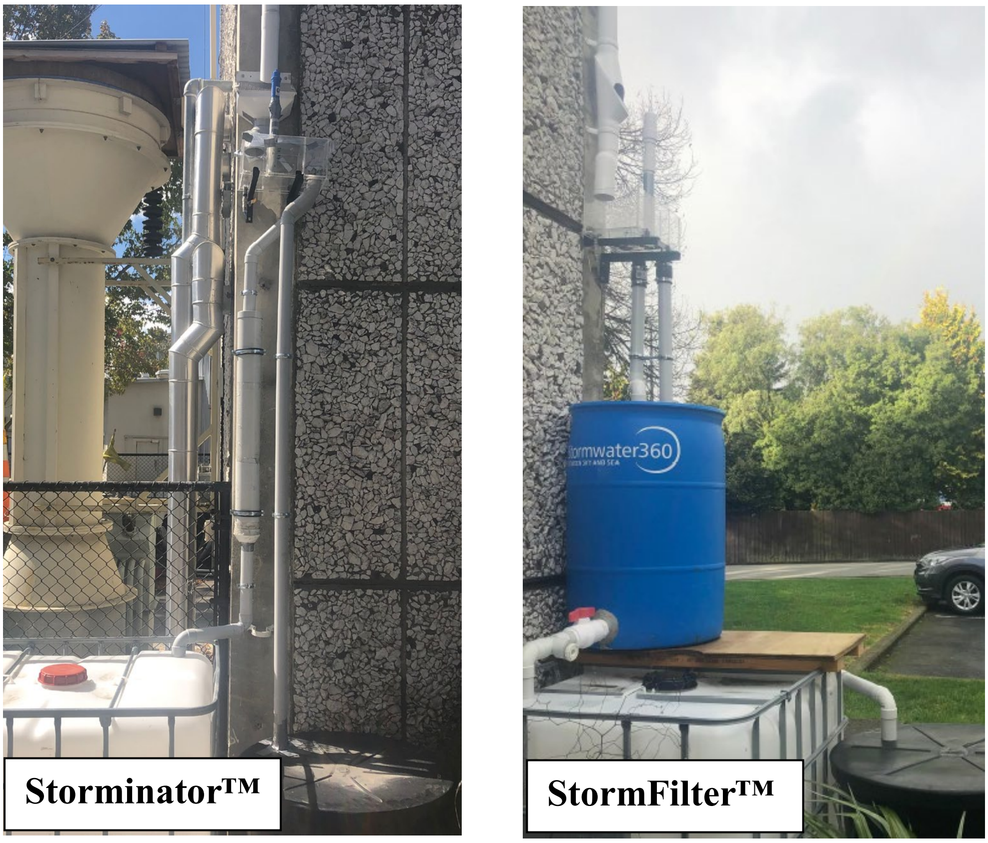

Figure 2: Storminator (left) and StormFilter (right) with collection tanks, weir boxes and leaf diverters.

RESULTS & DISCUSSION

Untreated Runoff & Storm Detail

Sampling occurred from 23 May - 30 November 2020 and included 22 unique rain events (Table 2) and a total of 200 mm of precipitation. Runoff to the downpipes favoured the south-west and north-east corners of the roof by a ratio of 2:1. The total storm volume captured correlated well with the total precipitation of each storm event, however, discrepancies were observed due to water loss from leaf diverters and clogging of the small (i.e. untreated) weir. Zinc loads in the sampled roof runoff generally consisted entirely of dissolved zinc. On average, the treatment systems showed a reduction in dissolved zinc; the untreated and treated concentrations were 201 µg/L and 52 µg/L respectively (Table 3).

Across all units, untreated pH averaged between 6.7 – 7.4, conductivity between 27 – 68 ms/cm and alkalinity between 4.0 - 7.4 mg/L as $CaCO_3$. Greater increases in these parameters from the untreated to treated quality samples were seen with the aged mussel shells (Table 3). As the StormFilters™ filled with runoff before syphon activation, the increased contact time increased pH, alkalinity and conductivity in treated runoff compared to Storminator™ results.

Table 2: Average event characteristics from monitored storms between 23/5/20 - 18/7/20 (Events 1-10) and 21/8/20 - 30/11/20 (Events 11-22). Separated between the operation of SN-SW1 and SN-SW2.

	Temp °C	ADD (days)	Total Precip (mm)	Average Intensity (mm/hr)	Peak 5-min Intensity (mm/hr)	Duration (hrs)
Mean value	10.0	4.8	9.1	1.0	5.4	13.7
Median value	9.7	2.7	6.6	0.7	4.8	8.6
Minimum value	5.5	0.3	1.0	0.1	2.4	0.3
Maximum value	16.1	19.6	37.2	6.0	9.6	44.5
1st 10 Mean	8.5	3.6	14.4	0.9	5.8	21.3
1st 10 Median	8.4	1.5	11.6	0.7	4.8	21.1
1st 10 Min	6.4	0.3	2.8	0.4	2.4	1.5
1st 10 Max	11.0	11.4	37.2	1.9	9.6	44.5
Event 11-22 Mean	10.4	5.5	8.7	1.2	5.1	12.7
Event 11-22 Median	10.0	3.6	5.0	0.8	4.8	8.6
Event 11-22 Min	5.5	0.3	1.0	0.1	2.4	0.3
Event 11-22 Max	16.1	19.6	37.2	6.0	9.6	44.5

Table 3: Average untreated and treated runoff quality results within monitored STSs

Parameter	**Treatment System**				
	SN-SW1	**SN-SW2**	**SN-NW2**	**SF-SE**	**SF-NE**
# Storms Sampled	10	14	20	11	9
Volume Treated (L)	648	321	278	167	369
Average Flow (L/min)	0.7	0.9	0.6	0.8	0.6
Change in Alkalinity (as $CaCO_3$)	6.5	11.7	11.7	61.0	48.7
Change in Conductivity (ms/cm)	13.8	21.7	24.3	177.3	143.5
Change in pH	0.6	1.0	1.0	2.6	2.7
Untreated Dissolved Zn (ug/L)	152.3	187.1	209.0	241.9	228.8
Treated Dissolved Zn (ug/L)	77.7	17.8	36.1	61.9	59.7
Dissolved Zn removal efficiency (%)	34	88	80	74	73

Variability in Treatment & Load

Individually, the treatment systems performed well with the exception of the original SN-SW1 which was filled with fresh mussel shells. Following consistent results of under 50% removal efficiency of dissolved zinc (Figure 3), it was removed and replaced with SN-SW2 containing aged media. Reduced performance was likely due to the relatively smooth texture of the fresh mussel shells and reduced specific surface area for treatment.

Preliminary data suggests that variation in untreated contaminant concentration is the driving factor behind variation in stormwater treatment system performance. All regression tests returned statistically significant results, however, individual p-values were not statistically significant (ie. $p > 0.05$) with several exceptions. The coefficients from regression analyses of StormFilter™ data (Table 4) showed that the untreated dissolved zinc concentration ($p>0.05$) is most influential in determining treated concentration. Coefficients from regression analysis of Storminator™ data, using removal efficiency as a predictor, showed untreated pH as most influential ($p>0.05$) followed by statistically significant untreated dissolved zinc ($p=0.03$). The influence of untreated pH may be due to the shorter contact time of the Storminator™ (as compared to the StormFilter™), however, further investigation is necessary to understand this relationship.

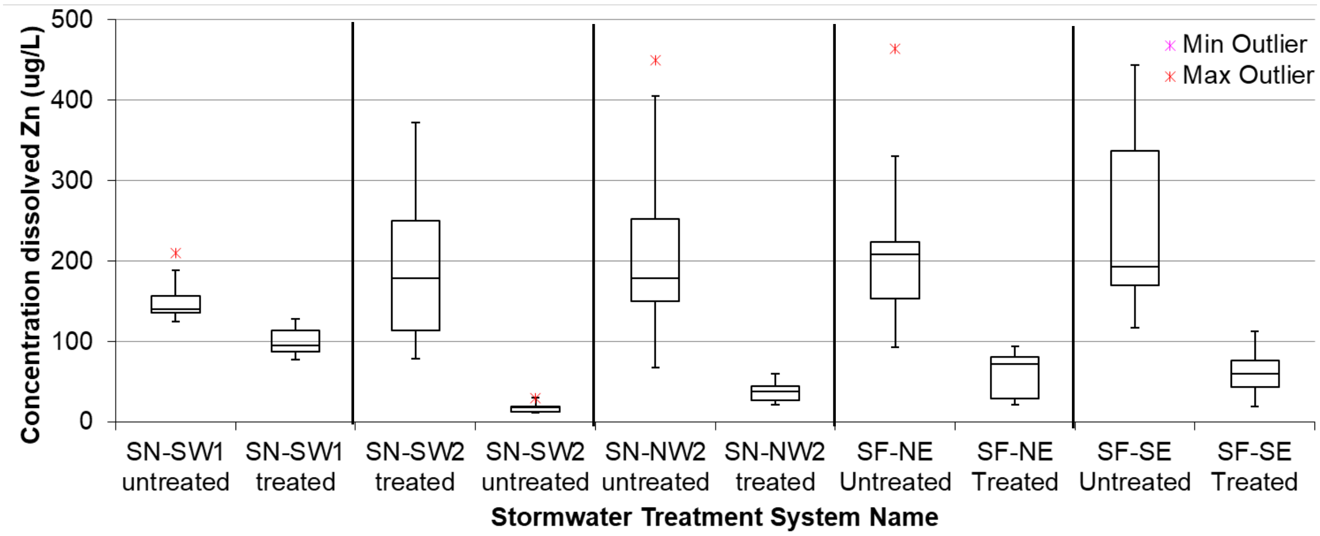

Figure 3: Untreated and treated concentrations of dissolved Zn in Storminator™ and StormFilter™ samples.

Table 4: Multiple linear regression results and linear coefficients for each test variable. A higher coefficient value indicates a stronger influence.

Predict dissolved Zn removal efficiency with Storminator™ data (27 samples)							
pH untreated	Untreated dissolved Zn	Conductivity untreated	Avg storm temp	Volume treated	Maximum flow	Alkalinity untreated	Flow duration
0.39	0.18	-0.06	0.06	0.04	0.04	0.03	-0.02
Predict treated dissolved Zn concentration with StormFilter™ data (14 samples)							
Untreated dissolved Zn	Avg storm temp	pH untreated	Alkalinity untreated	Flow duration	Volume treated	Maximum flow	Conductivity untreated
0.63	0.29	0.28	0.13	0.08	-0.08	-0.07	-0.06
Predict untreated dissolved Zn with all untreated runoff samples & events (56 samples)							
Avg storm temp	Peak intensity	pH untreated	Avg wind speed	Total rainfall	Antecedent dry days	Average intensity	Storm duration
0.61	0.60	0.46	-0.38	-0.24	0.15	-0.12	-0.07

Regression analysis was then undertaken to identify the primary influences on untreated dissolved Zn due to it having a substantial influence on both the Storminator and StormFilter performance. It showed average storm temperature ($p>0.05$) and peak intensity ($p=0.04$) are influential in determining untreated dissolved zinc concentration. Variation within the untreated dissolved zinc in the first ten storms (SN-SW1 untreated in Figure 3) is lower than untreated variation in other treatment systems. Not only was there less variation in storm characteristics during the first 10 storms, but the storms also tended to be colder and less intense (Table 2).

CONCLUSION & RECOMMENDATIONS

Treatment of runoff containing primarily dissolved zinc was investigated using two pairs of proprietary stormwater treatment systems, the Storminator™ and StormFilter™, filled with mussel shell media. Results were used to determine the most influential variables affecting variability in their performance. Variability in treatment performance was most influenced by untreated contaminant concentration and pH. The untreated contaminant concentration was most affected by storm temperature, rainfall intensity and pH. Sampling of future storm events is required to further build the dataset and gain more confidence in results. Analysis to date indicates that a third source of variation coming from different monitoring and sample collection methods would be valuable for further research.

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KEYWORDS

Stormwater treatment, mussel shell media, stormwater treatment performance.